GEOTEXTILE BAGS FOR SOLE PERMANENT BANK PROTECTION

Michael Heibaum[1], Knut Oberhagemann[2], M.A. Faisal[3] & Shahidul Haque[3]

[1] *BAW - Fed. Waterways Engineering and Research Institute. (e-mail: mhb@baw.de)*
[2] *Northwest Hydraulic Consultants Ltd.. (e-mail: koberhagemann@nhc-edm.com)*
[3] *Bangladesh Water Development Board. (e-mail: huq_shahidul@yahoo.com)*

Abstract: While geotextile bags and the whole family of geotextile containers are well established in hydraulic applications only a few specifications exist for such elements and for structures to be built with them. To choose a suitable fabric for severe hydraulic conditions, usually tests are recommended. If the fabric is not protected by an armour layer, additional mechanical loads on the geotextile have to be considered. Such loads can be covered by additional appropriate tests, combined with tests to check the resistance against installation impact.

Most of the hydraulic applications of geotextile bags are executed with an additional protection, only a few hydraulic structures are built with geotextile containers without any armour, e.g. scour protection around dolphins and sea- and river-groynes as hydraulic training structures. The use of geotextile bags as an exclusive revetment of a river is not yet established but offers the potential for successful functioning low cost solutions, especially in developing countries.

Since 2002, geotextile bags have been used in the Jamuna Meghna River Erosion Mitigation Project (JMREMP) in Bangladesh to face the problem of riverbank erosion. With traditional riverbank protection works failures were observed within a few years after construction. So a flexible approach was required, taking into account the variable river environment. Since often financial constraints limit such protection works, low cost solutions are sought. Therefore, sand-filled geotextile bags were chosen as protective elements, being much cheaper than commonly used concrete blocks, quarried rock or boulders and taking advantage of available inexpensive labour and locally attainable sand. The paper discusses necessary specifications, suitable test methods and experience gained during the first years of the Bangladesh project.

Keywords: geotextile bags, geotextile containers, revetment, erosion control, case study

INTRODUCTION

Most of the hydraulic applications of geotextile bags and containers are executed with an additional protection, only few hydraulic structures are built with geotextile containers without any armour. The use of geotextile bags as exclusive bank protection is not yet established but offers well functioning low cost solutions, especially for areas of low productivity and low economic output. Geotextile bags and containers are meanwhile well established in hydraulic applications. Nevertheless only few specifications exist for such elements and the structures to be built with. To choose a suitable fabric for severe hydraulic conditions, tests are recommended.

In Bangladesh geotextile bags of relatively small size (125 kg) are applied as permanent protection against riverbank erosion without cover layer, providing a continuous, multi-layer coverage to the eroding riverbank, including providing a wide apron as toe protection at the bottom of the river. This unusual approach was developed, driven by the need for protecting largely agricultural lands in a cost-effective manner against the widening of the major rivers.

GEOTEXTILE BAGS AND CONTAINERS FOR HYDRAULIC STRUCTURES

General

Geotextile bags and containers are multi-purpose elements. They can be manufactured according to any demand, concerning raw material, size, shape, filtration capacity, strength etc. They are prefabricated, but filled on site. The smallest type of containers, sand bags, can be used as a temporary cover layer, for instance for immediate protection of a scoured bank. The largest type is as large as a split barge, containing 300 to 500 m³ fill. With such elements, artificial reefs can be built, or longitudinal dikes or other forms of an active scour protection, or dams for land reclamation, etc. Always the size of a geosynthetic container has to be chosen such that the expected hydraulic load will not remove or transport the container. Geosynthetic containers can also be installed to form a filter layer when it is impossible to place a granular filter or geotextile filter. Neither a grain filter nor a geotextile filter can be placed when the flow velocity is too high. With an appropriate size and fill, geosynthetic containers may be placed even with high flow velocities.

Geotextile structures under hydraulic load usually are protected by an armour, but increasingly several types of structures are built without a protection layer. On one hand this is due to further development of fabric and manufacturing. On the other hand in many places there is no appropriate material available for hydraulic (defence) structures like armourstones, riprap or concrete elements. And a third reason gains importance: transportation time, e.g. for immediate defence works in case of disastrous events. In Bergado (2007) suitable methods for regions threatened by tsunamis are discussed by several authors. New design approaches for stacked containers are given and the forming of a detached breakwater by geosynthetic tubes is discussed, both not being covered by any armour. Tubes can be manufactured to great length without interruption, which promotes this type for long protection measures parallel the coast or a river bank. But any damage to a single long tube will cause the failure of the whole structure, if the tube is not separated into a number of chambers. The following discussion concentrates on bags and containers.

Large containers for breakwaters and artificial reefs

The traditional construction material for breakwaters and artificial reefs is rock or rubble mound. If such material is not available, concrete elements are used. Such structures are loaded by external and internal water motion and have to be designed accordingly. Breakwaters are built either low-crested, i.e. some overtopping will take place under design conditions, or submerged. Artificial reefs are always submerged.

Geotextile containers have been used in a large variety of forms for the last ca. 20 years to build coastal protection structures. Predominantly in Australasia such structures have been developed to such a stage that they can be regarded as providing a standard solution and not only an alternative construction method. In several cases, the traditional materials and their impacts and costs were hardly acceptable and therefore the geosynthetic solution (without an additional armour layer!) was preferred (Hornsey et al. 2002). Very large containers were used, to form an artificial reef at the northern Gold Coast (Australia). The reef was built by arranging nearly 400 containers of ca. 20 m in length and 3.0 to 4.6 m in diameter following a strict design based on model test and theoretical considerations.

Geosynthetic containers usually are filled with sand which gives several advantages: using locally available sand for fill keeps the costs low. The sand fill allows limited deformation of the container, so the container can adapt to an uneven subsoil and to the neighbouring element. Avoiding any hard elements and sharp edges that could pose some health and safety risk to swimmers, surfers and beach goers increases the leisure value of those parts of the beach needing a protection structure. The porous fabric of nonwoven casing makes it an ideal platform for marine growth like seaweed and the whole structure offers a habitat for many marine creatures (Jackson et al. 2004).

Medium sized containers for groynes and protection of sandy islands

The armour of coastal protection work often is made of rock, if available. Alternatively concrete elements are installed, but mostly causing higher costs. Such solutions are not possible if there is neither rock nor concrete available and transport distances are too long to carry or ship the armour material. WWF (2000) reports on examples on Islands in the South Pacific. On these islands coastal erosion endangers the beaches that are an attraction to tourists and therefore guarantee the living of the islanders. If these beaches were to vanish, so would the tourists, the most important economical factor in this region. Geosynthetic containers helped to solve the dilemma. The fabric is lightweight, so transport costs were limited despite the large amount of containers needed. Sand as a perfect fill material was locally available in any quantity and local labourers were easily taught to fill the containers correctly with simple equipment. Once filled and closed, the containers with ca. 1 m³ sand fill have sufficient resistance against heavy hydraulic impact from currents and waves. In this case, geosynthetic containers proved to be the only solution to the problem of guaranteeing beach stability, and therefore the livelihood of the inhabitants through tourism.

In Australia, 2.5 m³ containers were used to built a sea wall as emergency protection measure and, based on the success of this structure, several groynes. These proved being stable under severe wave attack and due to the vandal deterrent fabric resistant against non hydraulic action.

Bags for emergency and permanent protection

Sandbags have been long known, for example, as immediate scour repair of dikes during storm surges, as protection against rising water during floods, as protection or confinement of sand boils at the landside of dams and dikes, or as a toe filter. Sandbags have been used as a temporary cover layer, for instance for bank protection. The lifetime is limited due to weathering. Under water, weathering is not much of a problem, so they can be used, for example, for scour protection at bridge piers or dolphins. In most cases the bags are covered by a protection layer, but they might be left without armour if hydraulic stability is provided. Pilarczyk (2000) reports that tests showed stability of bags of 30 litres (45 kg) when loaded with a current of 2 m/s and cites Bruinsma who found stability until 3 m/s (p. 289).

Literature is very sparse concerning bags loaded by current. So there was only few experience when a project in Bangladesh to stabilize the river banks was started (Oberhagemann and Sharif-Al-Kamal 2004, and Oberhagemann et al. 2006). There are shortages of local aggregate for concrete and no suitable rock for riprap. But there are resources as sand and labour. Therefore the attempt was started to use geotextile bags filled with fine river sand for bank protection. Details are given in paragraph 4.

CONTAINER FABRIC

For a safe placement, for high serviceability and for sufficient long term resistance, the container material has to be chosen such that it will resist all mechanical loads. Usually there is a choice of wovens and nonwovens. The first have the advantage of high tensile strength, the second the advantage of large straining capacity. If the containment is damaged, a woven cloth might be more susceptible to crack propagation (the zip effect) than a nonwoven. Nonwoven fabric usually has a high straining capacity, so the tensile strength may be less to provide a similar resistance against mechanical impact. By allowing large deformations it will be able to withstand the impact load when hitting the ground as well as when the stones are dumped upon

Since the container has to sustain abrasive forces due to rocking armour stones or, if not protected by an armour, due to sediment and bedload transport, any geosynthetic material used for containers needs a high resistance against abrasion. This requirement is fulfilled more easily by nonwoven fabric.

If containers are additionally exposed to sunlight for at least some time, the fabric needs a sufficient resistance against weathering in general and against UV radiation in particular. Today long lasting solutions are possible as for example groynes in Australia that did not show degradation after 10 years (Hornsey et al. 2002).

TESTS ON BAG AND CONTAINER FABRIC

Filtration

Holtz et al. (1997) consider a filter design based on index tests (thickness, mass per unit area, opening size) not sufficient for erosion control and scour protection measures under severe conditions. Loads like reversing flow through the geotextile like e.g. in filters for revetments and similar systems are not covered by the usual design based on the opening size of geotextiles – so tests are recommended (BAW 1993). In Germany performance tests (flow-through method or reversing turbulent flow method) according to the regulations RPG (1994), are mandatory for inland waterways.

The importance of such tests for geosynthetic bags and containers depends on the whole system: If the flow through the protection system does not cause a significant load to the system, the main task of the geotextile is to retain the fill and the soil. So a tolerable maximum opening size is the governing parameter (beside the parameters concerning robustness and durability). If water levels behind and before the protective system (or on both sides of a geotextile layer) show such a difference that an essential flow with a corresponding high gradient is created, filter properties have to be checked carefully by tests as mentioned above.

Abrasion

One important criterion of robustness of a geotextile is the resistance against abrasion. Abrasion is caused by rather different loads, so tests have to be chosen according to the application.

As an early abrasion test, the "sliding block method" for geotextiles was developed (ASTM Test Method D 4833 – 88: Abrasion Resistance of Geotextiles (Sand Paper/Sliding Block Method)). Unfortunately this test takes account only a loading that simulates the sliding of a solid mass over carpets or seat covers etc. The contact of soil and geotextile is different! Soil is not a solid surface that slides as a block over a geotextile specimen. The soil grains do not behave like a rigid surface, but roll, tumble, rock or draw off. Therefore interaction of soil and geotextile is not represented by such a test. Additionally, concerning the use of geotextiles in hydraulic applications, most of these tests are not adequate since they are performed in dry conditions.

Since no general EU- or USA-test is known as to abrasion of geosynthetics, BAW developed an abrasion test for hydraulic application (RPG 1994). This test can be considered representing best the abrasive load induced by any hydraulic processes. Recently a test with similar objective was proposed by Huang et al. (2007). In a circular flow chamber, the geotextile is exposed to a flow with a certain particle concentration. First results were gained with woven fabric, but no long-term experience with woven and nonwoven fabric can be provided as with the BAW test.

Figure 1: BAW Abrasion tester

The load imposed on the geotextile in the BAW abrasion test represents the load in situ very well, since it is performed in the wet and the abrasion is caused by particles tumbling over the fabric. In situ sediment and bedload transport applies just such a load on the geotextile. Recovered samples that have undergone severe sediment and bedload transport show a nearly identical damage like fabric that was tested in the BAW abrasion tester.

In this test, a mixture of stone chippings and water passes over geotextile samples installed in a rotating drum. The standard test comprises two abrasion phases of 40,000 revolutions each. The drum speed is set at 16 rpm and the direction of rotation is reversed every 5,000 revolutions. The samples are visually checked after the first 40,000 revolutions. If the samples are not degraded new stone chippings are filled in and the second phase is carried out. If the samples have not been destroyed after 80,000 revolutions, samples are taken from the centres of the abraded surfaces and their tensile strength is tested.

The tensile strength after abrasion is tested in the direction of abrasion load, i.e. in the longitudinal direction of the sample (200 x 300 mm) Due to the sample size, testing according to EN ISO 10319 is not possible (only an area of 170 x 280 mm is loaded, the margins are protected). Therefore tensile strength is tested according to RPG (DIN 53857: specimen size 100mm width x 200mm length, deformation rate 200 mm/min). For reason of comparison, the sample has to be tested the same way before the abrasion test as after the test. The tensile strength according to RPG is in most cases equal to the tensile strength according to EN ISO 10319, even though the test procedure is somehow different (specimen size 200mm width x 100mm length, deformation rate 20% / min).

Eight samples undergo simultaneously the abrasion test according to RPG. Four are loaded in machine direction and four in cross machine direction. A geotextile is considered resistant to abrasion loads if 75 % of the required layer thickness and of the required tensile strengths are still left after execution of abrasion test. The remaining tensile strength should be given in strength units, not in percent, since often fabric is offered that shows higher virgin tensile strength than required whereas it experiences a larger loss than 25%, but still meeting the absolute threshold value of 75% of the required tensile strength.

The values required in specifications for this test are minimum values, so every sample has to fulfil these requirements. Therefore the definition of a mean value and standard deviation is not decisive, which allows the testing of only a reduced number of samples.

Abrasion-test extension

It is a fact that after an abrasion test some fabric still shows significant tensile strength even though there is no filter function due to holes in the fabric. Therefore it is considered not sufficient to test the remaining tensile strength after the abrasion test as requested by RPG (1994). It must also be guaranteed that the opening size and thus the filtration capacity has not changed in an unacceptable manner. The opening size should not increase the opening size required in the filter design more than 0,01 mm to guarantee sufficient filtration function also after a certain amount of abrasion.

BANGLADESH CASE STUDY

General

Since 2002, geotextile bags are used in the Jamuna Meghna River Erosion Mitigation Project (JMREMP) in Bangladesh to face the problem of riverbank erosion. With traditional riverbank protection works failures were observed within a few years after construction. So a flexible approach was required, taking into account the variable river environment. Since often financial constraints limit such protection works, low cost solutions are sought. Therefore sand-filled geotextile bags were chosen as protective elements, being much cheaper than commonly used concrete blocks, quarried rock or boulders and taking advantage of available inexpensive labour and locally attainable sand. The first 10 km of protection have been built to different levels of completion along the banks of the Brahmaputra / Jamuna and Meghna in Bangladesh.

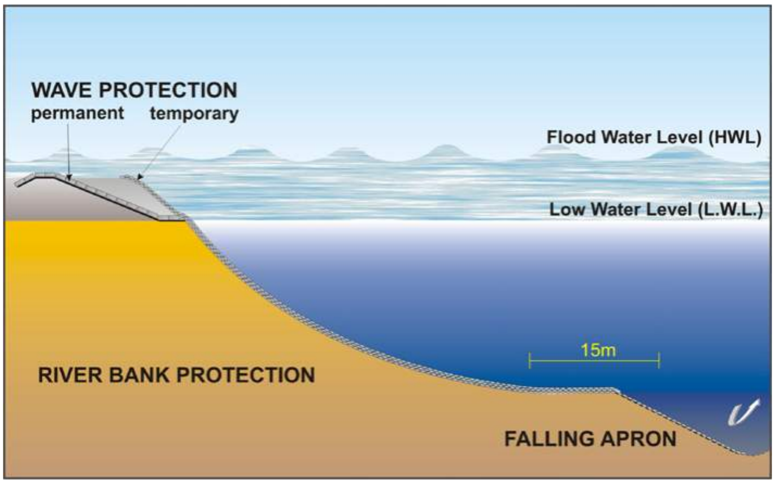

Figure 2: Geotextile bag revetment

The country is the lower riparian country of the three rivers Ganges, Brahmaputra, and Meghna. These rivers flow through alluvial plains build over million of years from the materials shed off instable slopes of the Himalayas. Consequently, rivers in Bangladesh are characterized by great instability, with (i) deep scouring, exceeding locally 70 meters in depth, (ii) very high discharges, exceeding 150,000 m^3/s during the 100 year flood, with high flow velocities in excess of 4 m/s at exposed places, and (iii) no rock quarries providing the commonly used cheap material for riverbank stabilization.

In this environment riverbank protection was long tried with limited success, mainly due to the high cost, caused by the replacing rock through expensive surrogate concrete blocks for bank protection. Driven by the urgent need to protect two large irrigation schemes where the conventional type of riverbank protection was not economically feasible, a new path was followed using sand-filled geotextile bags.

Loads

Riverbank protection using geotextile bags has three main loads beyond the normal use: (i) ultra violet radiation (above water), (ii) wave action (above water), (iii) abrasive attack through sediment transport (below water).

The ultra-violet radiation could be taken into account through the use of additional protective layers, however at the cost of increasing the price. In the Project the problem was solved by placing the bags above water level only as temporary wave protection for about two years until the land-acquisition process is completed and the temporary protection is replaced by a geotextile filter layer covered with hard materials such as placed concrete blocks. This provides the additional advantage of reducing pilferage of the geotextile bags, which are used for multiple purposes by the poor local population and avoiding damages with high maintenance effort.

Wave action affects geotextiles as it loosens the internal bond. Experience from South Africa for example with silt-curtains used during dredging operation indicates that continuous filament is more susceptible than staple fiber (personal communication). Interestingly the abrasion test of BAW (RPG 1994) shows similar behaviour under abrasive load.

Abrasion is a major concern, as it is an additional load that normally does not apply to geotextile filters. However, in unusual circumstances, for example geotextile filter layers under rock riprap in stilling basins, abrasive action once the rock moves could abrade the filter. The BAW's rotating drum test was developed for this type of load. Considering the high sediment load in the main rivers in Bangladesh, sediment transport could play and important role if continuously passing along the unprotected geotextile surface of sand bags. A simple example explains this: assuming an average flow velocity of 1 m/s, transporting sediment along the river bank during the four main monsoon months of a year, results in a relative length of 300,000 km of transport length in 30 years (1m/s * 60s/min * 60min/hr * 24hr/d * 120d * 30yrs). Even though the main attack is not always at the same level under water and the sand grains are under uplift pressure, the resulting load could be sufficiently large to damage the geotextile in the long-run. Hornsey et al. (2002) recommend BAW's abrasion test for the abrasive environment of coastal protection and in fact it is the only existing test that simulates this type of attack.

Figure 3: A geobag from the wave zone at the Bahadurabad test site at the Jamuna. The bond between the fibers is destroyed and the bag open. The bag was placed in early 1997. The photo was taken in early 2005.

Fabric

Even though thickness is one of the most important robustness factors, in the beginning of the Project it was tried to reduce the thickness of the geotextile as much as possible, due to the need for cost minimization. Suitable material is non-woven, as the fine- to medium-grained sand locally available has a D_{50} of about 0.2 mm, which is close to the minimum available O_{90} of ca. 0.08 mm. Woven material commonly has an O_{90} above 0.1 mm, which was considered to be too porous. After abrasion the geotextile material is not allowed to loose its sand-tightness, as otherwise the bags would leak the material out over time and loose their weight and consequently stability to hydraulic loads. Furthermore, the bags will not function as a filter, protecting the subsoil from erosion.

Abrasion tests

Tests carried out in 2002 on new fabric designed for geotextile bags showed that higher mass per unit area increases the resistance and staple fibres showed less strength loss after abrasion then endless fibres. But it showed that it is also a question of thickness and many more factors, so discussion started on the parameters and tests required for geotextile bags. In the Project the conventional abrasion test was extended by further asking for the comparison of the O_{90} before and after testing, as important parameter to identify if the bags would leak the sand out over time. Systematic investigations with BAW's rotating drum test indicate that staple fibres are less susceptible to abrasion than continuous filament.

Thickness always has to be considered parallel to the mass per unit area, as it turned out during the first procurement contracts, starting with minimum specifications of 3 mm at 300 g/m² that no supplier could provide. A material this light could not fulfil the other requirements. The minimum mass reached about 380 g/m². Finally the thickness requirement was dropped and the mass increased to 400 g/m².

Bag stability

The stability of the geotextile bags under water is further confirmed through diving tests. Some diving took place during major flow attack, reaching velocities above 1 m/s at the surface. The divers are able to "climb" down the protected slope by holding to the bags. The applied extra load of the diver's drag does not move the bag, not even the lighter 78 kg bags. Even under velocities at the limit of diving, it was very difficult to move 78 kg bags under water, meaning to turn them. It is impossible to lift the bags up. In contrast, the lighter ones, 36 kg and 11 kg are easy to move or even lift and could be transported by the flow. This is the main reason to discourage their use, as to avoid gaps in the protection after their mobilization through flow forces.

Installation

The main load applied on the sandbag is during impact after dumping. This load however is small (Individual Consultants, 2003). To test bags to the maximum of their performance, filled geotextile bags were dropped from 10 m height on a concrete surface. The impact velocity from this height is around 50 km/h whereas the maximum velocity from the fall through water is between 13.7 and 9.7 km/h, only one fifth. The result is that the geotextile only experienced very low strain (maximum elongation 5%), without any seam breaking. The Project nevertheless requires to use Type 402 seam (two parallel lines of double thread chain stitch) along the sides of the bag and four lines of type 101 seam (single thread chain stitch) to close the bag. While two lines are stitched straight the other two lines form an arc, starting below the straight seams at the edge and run above the straight seams in the middle. In this way the lock the first two seams at the end additionally and they provide a greater length, which acts as additional safety measure in case the geotextile is elongated.

As bags are dumped from barges with the intention to form a uniform coverage of the riverbank under water, the dumping behaviour of bags plays an important role. This is difficult to observe and monitor, as the river water is murky and does not allow visual inspection. Nevertheless, first dumping tests were undertaken in still water conditions (Zellweger, 2007) that show that geotextile bags always fall in the same manner and that stacks of bags reach the bottom together. We assume that under flow certain differences will occur, as reported from physical hydraulic model tests (Vancouver model). More systematic tests are planned in future.

Implementation and Performance

Revetment work in main rivers in Bangladesh can only be implemented in a phased manner, as a consequence of fast river changes, and great variability allowing prediction of riverbank erosion only one year ahead. In the Project three main phases are distinguished: (i) mass dumping along the eroding river bank as emergency response to protect valuable infrastructure, before the monsoon season, (ii) main protection consisting of applying systematic protection from the river, implemented after the monsoon season, and (iii) adaptive protection, building the work to greater depth if the erosion continues and threatens to undermine the exiting work during later years.

All three types of work have been applied along about 10 km of riverbanks in Bangladesh. The systematic dumping from the surface, even without taking cognizance of flow displacement, results in systematic coverage of the underwater bank slopes with multiple layers as confirmed through diving.

While the bags are initially soft the sand consolidates after a short time (months) and the bags feel later as hard as concrete. The surface of the bags often keeps an undulated pattern, resulting from the impact. In addition, bags develop over time some bio-skin, consisting of algae in areas where light penetrates and other life forms (such as little worms building shelter tubes consisting of mica-flakes) in areas with less light. This coverage provides extra protection to abrasion and indicates that the bags could last longer than expected.

In cases and as a result of the consolidation of the sand the sand volume reduces while the geotextile volume remains the same. Full bags above water turn into partly filled bags under water. As a consequence some corners could become loose and start flapping in the flow. Until this moment there are no signs of fatigue and we do not expect that this plays a major role. The reason is that the material is quite thin and therefore not as susceptible to fatigue as the very thick material (in the order of cm) of mega-containers for example.

Apart from the stability of the cover layer, geotextile bags fulfil the requirement of launching as toe protection on geotechnically stable slopes. Latest river surveys confirm this behaviour: bags placed at the end of 2006 have started launching after the river deepened during the high 2007 flood. Bathymetric surveys show that the slopes after launching are in the order of 1V:2H even though the falling apron was placed in parts in areas that consisted of recently deposited sands and not of old consolidated sands at the bankline. Supporting divers observations indicate that even though the coverage after launching is only a single layer of bags, the gaps between different bags are small. One is only able to put a hand through. The plastic behaviour of launching bags through the readjustment of the sand-fill apparently keeps the gaps small and as such reduces the loss of underlying fine material. This observation supports the quality of geotextile bags as flexible riverbank protection even in the extreme use as falling apron on unstable developing slopes.

SUMMARY

Geosynthetic containers are still not very well known. But increasingly often, they prove to be able to replace other elements in many structures, especially in hydraulic works. They can be adapted to the individual application in form, strength and permeability. Often their application results in lower costs compared to traditional construction methods.

Only few approaches for planning and design are available (e.g. Pilarczyk 2000), so the best approach to check the applicability are tests representing the situation in situ. If the bags are not protected by an armour, abrasion is of major concern. The rotating drum test (RPG1994) allows to estimate the behaviour of any fabric when loaded by sediment and bedload transport.

Based on this test, fabric has been chosen for riverbank protection using geotextile bags of relatively small size (125 kg) as permanent protection against riverbank erosion without armour layer in Bangladesh. After two high flood seasons (2004 and 2007) no failures were found and the work performs well.

Corresponding author: Dr Michael Heibaum, BAW - Fed. Waterways Engineering and Research Institute, Kussmaulst. 17, Karlsruhe, D-76187, Germany. Tel: +49 721 97263820. Email: mhb@baw.de.

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